Comparative analysis and feasibility study of foundation projects for IFG - campus Aparecida de Goiânia

Arthur Duarte Dias
University of Brasilia, Brasilia, Brasil, engenho.arthur@gmail.com

Laís Magalhães Wind[1], Arlam Carneiro Silva Junior[2],
Federal Institute of Education, Science and Technology of Goiás, Aparecida de Goiânia, Brasil, laiswind@gmail.com[1], arlamjr@gmail.coml[2]

Renato Pinto da Cunha[3]
University of Brasilia, Brasilia, Brasil, rpcunha@unb.br[3]

ABSTRACT: Soils composition varies according to many aspects and therefore it cannot be guaranteed that the properties will be the same from one point to another, even if nearby. Thus, geotechnical investigations in the area of reference to the project are of utmost importance as they provide to the foundation engineer technical support based on soil study reports in order to find the best foundation solution for the site. Based on this, the objective of this research is to compare the performance in terms of strength and feasibility of four foundation sizing solutions for the expansion of the Civil Engineering Technological Building at the Federal Institute of Goiás (IFG), Aparecida de Goiânia campus. Thereunto, the research consists of analyzing the geotechnical properties of the study area, mainly through the SPT test and then evaluating which type of foundation is most suitable for future construction. From the results, it can be said that the properties of the studied soil are consistent with the region where it is located. The load calculations and the feasibility studies indicate that there is a range of possible foundations, being the caisson type the most feasible to be performed at the site.

Keywords: foundation; feasibility study; bearing capacity; geotechnical characterization

1. General instructions

The soil is formed by a set of particles, water and air that are grouped by physical and chemical weathering processes on the rocks. Particle size, water content, and plasticity help determine soil stability in response to loading forces of traffic, cultivation, or building foundations [1]. Because of the wide variation in formation, there is also a very wide variety of soil types, each with its own peculiarities. Even if a point on the ground has certain characteristics in its superficiality, it may have different characteristics as it deepens. Thus, geotechnics has improved over time to classify soils and evaluate their carrying capacity.

For many years, building foundations have always been associated with local culture and empirical methods. However, with the emergence of tall buildings, there was also the need to improve both the study of soil mechanics and the study of the foundation structure, responsible for transferring the loads of buildings to the ground. According to Vargas [2] foundations in Brazil began to be more widely known from the 1930s when buildings built in reinforced concrete already used direct foundations as a foundation for shallow foundations. For situations where deep foundations were used, the use of wooden piles or precast reinforced concrete piles was used. As for the state of Goiás, especially in the capital Goiânia, the foundations area had its peak since the 2000s when there was an upward warming of the real estate market and the verticalization of the city [3].

So it can be said that Soil Mechanics and Foundations are branches of engineering that study the behavior of the structure-soil system when stresses are applied or relieved. Das [4] states that these two subareas have developed rapidly over the past fifty years and that intensive research and observation, both in the field and in the laboratory, have refined and improved the science of foundation design. Foundations projects nowadays have scientific testing procedures to assist in the analysis of soil properties and thus optimize projects to the maximum. In other words, investigation of the properties of the subsoil is essential to design the distribution of loads on the ground in the most appropriate way.

One of the allied procedures of foundation engineers is the Standard Penetration Test (SPT) which was the main method of soil data collection used in this work. Due to advantages such as low cost, simplicity of operation and obtaining a numerical test value that can be related through direct proposals with empirical design rules, the SPT test is the most widespread and used in the technical environment [5].

After analyzing the results of the underground investigation, there are inevitably frequent questions about which type of foundation to build, not only because of economic aspects, but also because of other factors such as runtime, local availability, performance, endurance, productivity, and manpower qualified work. Aiming to deepen the technical knowledge in the area of Geotechnics and to achieve the objectives of this research, topics such as foundation design, drilling, soil characterization tests, methods of calculating load capacity, strength and design of structures, cost and execution of foundations, among others, will be covered in the following chapters.

2. Objective of research

Separated into general and specific, below are the objectives of this paper.

2.1. General objective

The general objective of the research is to compare the strength and viability performance of four foundation sizing solutions, for the particular case of the expansion of the Civil Engineering Technological Complex at the Federal Institute of Goiás, Câmpus Aparecida de Goiânia.

2.2. Specific objectives

The specific objectives of this research are:

- Analyze the survey results obtained;
- Conduct moisture content tests for samples collected meter by meter by drilling;
- Perform tactile-visual analysis of the collected samples and classify the collected soil meter by meter;
- Calculate load capacity and ground resistance for drillholes;
- Trace the soil profile from the test analyzes;
- Analyze the feasibility of executing four different types of foundation in view of the advantages and disadvantages of each one;
- Raise the basic execution costs of each of these four types of foundations, taking into account the average costs in the metropolitan region of Goiânia in labor, materials and machinery employed;

3. Background of analysis

Foundations are structural elements that pass the full load of buildings to the ground. There are historical records of foundations since prehistoric times when man had already dug wooden piles into the ground to support buildings. Over time, new materials and tools were being discovered, so the ways of building were modernizing, becoming more complex. Thus, it was through case records and empirical knowledge that foundation studies were advancing and becoming what they are today

One major contributor to advances in soil studies is Terzaghi, considered to be the father of soil mechanics throughout the geotechnical academy. He was responsible for collecting practical information from the earth and gathering it into an organized and realistic set of knowledge.

3.1. Foundation Design

Preliminary activities for the foundation design consist basically of the characterization of the area to be built through the study of the terrain and geotechnical investigations. The first is to collect data from the area where the building will be built, such as topography and data from neighboring buildings. The second objective is the geomorphological characterization, with the typification of the soils and rocks that occur there and precise definition of the horizontal layers of the soil and the water level. With regard to geotechnical investigations, Velloso and Lopes [6] consider the following research work as a minimum:

- Site visit for on-site knowledge of the terrain, neighborhood, and geological and geographical (including topographic) constraints of the site;
- Performing simple recognition polls (percussion polls or SPT polls). In the impossibility of performing simple recognition surveys (due to the presence of boulders, debris, rock or natural stone obstructions), the authors also recommend the execution of rotary surveys or mixed rotary / percussion surveys, with the guidance of a geology professional.

After the investigations are completed, the designer will have the technical basis to make the choice of foundation to use. This process includes a feasibility study of the foundations available in the market, as well as knowledge of the characteristics of each one.

Once the preliminary choice of foundation type is made, then the basis for project design through the sizing of the elements is provided. The basis of the calculations is to analyze the load capacity of the ground, ie the load resisted at the breaking limit. Briefly, the technical quality of foundations can be seen from three aspects: project quality, quality of foundation execution and quality of the finished foundation [7].

3.2. Soil investigation

According to Milititsky *et. al.* [7], the lack of soil investigation is the most frequent cause of foundations problems, and 80% of the cases of poor performance of small and medium sized works occur due to the adoption of inadequate solutions. from the complete absence of soil investigation. To emphasize the importance of underground investigations, engineer Zaclis [8] in an interview with Techné magazine pointed out that the foundation designer works hard on intuition beyond knowledge and therefore needs to rely on soil study reports and his own. experience on the region's soils. Because of this, it is also important to perform the tests with rigor to the standards, using standardized and verified equipment, trained teams in qualified and suitable companies.

Scarabel [9] also states that one of the most important steps for the study of foundations is the drilling and through the samples taken from this test it is possible to obtain important information about the local soil, such as: resistance, terrain characteristics, type of soil and its moisture and groundwater location. In addition, test results are used in many semi-empirical applications such as predicting the allowable stress of direct foundations in granular soils that can be accurately estimated by drilling. Some other common types of subsurface investigation procedures are: Cone Test (CPT), Pressiometric Test (PMT), Wells, Auger Drilling, Drilling, Rotary Drilling, and Mixed Drilling.

Standard Penetration test measures soil resistance along the drilled depth. It was developed mainly to obtain a local soil resistance measurement in the field, to collect soil samples at each perforated meter and to determine the water level position [10]. Câmara and Pereira [11] consider this type of drilling as an efficient measure to help in choosing the type of foundation to be used since a well-conducted drilling brings results that directly influence the safety standards, quality and economy of the work.

The standard execution of this geotechnical procedure (SPT) is basically the penetration of a standard sampler into the ground by free falling a weight of 65 kg at a height of 75 cm until the sampler penetrates 45 cm from the ground. Every 15 cm forward, the number of strokes required for this penetration is counted and the sum of the number of strokes required for the last 30 cm to penetrate the ground is called “N”. Subsequently, the hole is drilled meter by meter, taking the sample taken from the sampler base. The drill stop criterion varies according to the depth to be reached. In general, the procedure is stopped when a high number of blows are required to deepen the standard pile in the ground, or when the ground becomes impenetrable, thus preventing the advance of the holes. After the drill has been completed after at least 12 hours and the hole is unobstructed, the position of the water level should be measured if it has been reached in the test.

SPT is used in many applications such as prediction of the permissible stress of direct foundations in granular soils, classification of soil type and its resistance, subsidy in choosing the type and size of foundation types to be used in a structure, among others.

From the soil samples extracted meter by meter through the survey, a tactile-visual analysis should be made. First, samples taken at each meter should be labeled with the following information: site name, site name, number of holes, sample depth range, and date of collection. This storage of the samples is important for later a detailed description of the material obtained in the survey as a color; mean grain change; degree of grain fracture; and medium texture [12]. The characterization of soil type (plasticity limit, liquidity limit, particle size analysis and compaction tests) can also contribute to solve foundation problems, as it is an effective auxiliary tool in the tracing of underground geotechnical profiles, especially in large works.

3.3. Types of foundation most common in Brazil

Engineers need to know the applied efforts on building, soil properties and the main characteristics of foundation types. For this, the professional should be based on the types of foundations available in the local market and the main distinctive of each one. From this, one can choose the one that best meets the technical, economic and term conditions of the work. In densely populated places, it is also important to check the noise level of the equipment to be used. Thus, it is not possible to generalize which is the best type of foundation, as each case must be analyzed separately [13]. Basically, there are two types: shallow foundations and deep foundations, defined by [14].

Shallow foundations have foundation elements where the load is transmitted to the ground, predominantly by the pressures distributed under the foundation base. The excavation depth is less than 3 m and is used in light loads such as homes or in the case of firm ground. Included in this type of foundation: footings (racing, associated or boundary), block, raft pile and foundation beam. In another direction, deep foundations are those in which the elements transmit the load to the ground from the base, the side surface or a combination of both. They are used in cases of large projects, such as tall buildings, where wind stresses become considerable and in cases where the ground only reaches sufficient resistance at great depths of more than 3 meters. The most common types are piles, caissons and drilled shafts. For this work in question, four types of foundations are considered more relevant to further study, namely: footing, caisson, excavated pile and auger cast pile. Below is a brief description of each together with the methods of calculating load capacity and sizing of each.

- **Footing**: According to NBR6122 [14], a footing is a surface foundation element of reinforced concrete, dimensioned so that the tensile stresses produced in it are not resisted by the concrete, but by the use of reinforcement. They are the simplest type of foundation among all foundation types and often do not require skilled labor. Its use is restricted to small to medium size structures in non-compressible soils and where there is no water present in the soil, ie, they should be performed above groundwater level. Through its base the element transmits the loads to the ground, so they are classified as shallow foundations. Footings are considered rigid or flexible, depending on their height / dimension ratio, and their geometry can be classified as running, circular, square or rectangular footings.

- **Caisson**: A deep foundation of cast-in-place concrete that transmits structural loads to the highest bearing soils. They consist of jacking the shaft structure with concrete rings or steel caisson. They can be open air, with and without shoring, and compressed air, with metallic or concrete coating. This type of foundation is widely used in the construction of bridges and viaducts, requiring attention to the compatibility of the base material with the adopted design tension and ground instability. One of its biggest advantages is the low cost of equipment mobilization and the possibility of changing its diameter and length during its execution. However, it is a dangerous executive process since manual excavation practices are used in its execution, thus increasing the risk of death of employees involved in the procedure.

- **Excavated pile**: The excavated pile is characterized by being cast in place after digging the soil. This type of foundation is executed through metal towers, supported on metal chassis or coupled to trucks. In both cases, winches, traction assembly and hydraulic drilling rod are used, constituted by augers at their end, proceeding through telescopic extension. The advantage of this solution is the great mobility and production of the equipment, allowing the sampling of the excavated soil, reaching the design depth and the absence of vibration, and can be performed close to the border without damage to neighboring buildings.

- **Auger cast pile**: According to NBR 6122 [14] auger cast pile is a type of deep foundation made of concrete, cast on site and executed by continuous auger and concrete injection by the auger stem itself. This type of foundation is growing a lot in the state of Goiás due to its availability and productivity [3]). The advantages of this type of pile is that it is not restricted to the presence of water level, has no vibrations in the executive process, penetrates into more resistant soil layers, has electronic depth monitoring and high drilling speed.

3.4. Bearing capacity of soils

According to Ferreira [15], one of the biggest challenges of civil engineering when it comes to foundations is the calculation of the foundation structure and, mainly, the determination of the load capacity that the soil supports. He further states that once the load capacity and also the allowable stress of the soil are defined, resistance parameters must be adopted for the materials involved in the executive process and consider the coefficients required in the technical procedure, to finally perform the calculations that define the geometric dimensions and the amount of steel / concrete the foundation will require to meet its strength limit and not break.

Terzaghi in 1943 defined that there are two types of rupture, namely: general and local rupture (later known as puncture rupture, by Vesic). General breakage occurs most often in compact or hard soils, these soils have higher strength. Since local rupture generally occurs in medium compact sandy or medium clay soils, the deformation occurring in the soil by this type of rupture is classified as plastic.

In order to prevent a work from rupture of any kind, it is necessary to calculate the soil resistance in advance. Concerning this concern, several authors such as Terzaghi, Vesic, Aoki-Veloso, Decourt-Quaresma, Skempton, Meyerhoff have studied further and developed empirical methods on the allowable load and stress capacity in the soil. This paper focuses on the Terzaghi Theory and Empirical Methods that is used for the determination of load capacity and footing sizing and the Decourt-Quaresma Method that has the same use, but for piles and caissons.

In addition to Terzaghi, who focuses his studies on footing calculations, other researchers have also developed other methods for the same purpose, which are considered empirical. Ferreira [15] says that the methods considered empirical are the ones that most efficiently meet the safety and economy conditions, since they take into account both the ground test results (such as SPT and CPT) and the allowable stresses. . The use of these methods to calculate load capacity is the most used practice in foundations project offices in Goiânia and throughout Brazil [16]. The empirical methods are regulated by [14] and consider a safety factor of 3 which makes the load capacity calculations performed through it more reliable as the structure strength.

4. Methodology

The preliminary analysis of the area consists in raising the general characteristics of the terrain as well as its geotechnical properties. Initially the SPT polls were performed. The probing procedures were performed by the foundations company Brasil Fundações, headquartered in the city of Goiânia - GO. All tests were performed to the maximum penetrable depth possible and a piezometer was installed in each hole to check the water level 24 hours after each test which will also allow water level monitoring at any time of the year. This is important as the water level may make some types of foundations unfeasible. The choice of hole locations was based on architectural and topographic design. Thus, the drilling of the 3-hole drillings was planned to take place between the first and second semesters of 2017. The location of the holes was made by verifying that each point could reach the highest level of ground recognition range. In addition, it was decided that the first three drill points would be aligned in order to obtain the soil type profile per meter depth, and a fourth drill was made south of the other three in order to identify possible differences between soil type, groundwater level and resistance. The location of the perforations and their order will be displayed in the search results.

Soil samples collected meter by meter were subjected to tactile-visual analysis and moisture content tests. They were stored in capsules and then the capsule-ground sets were weighed. This material was taken to the greenhouse, where it remained for 24 hours and then weighed again to determine the amount of water evaporated. Thus, it became possible to obtain the percentage amount of water in the sample. The standard that governs the humidity test is NBR 6457 [17]. For tactile-visual analysis, a quantity of sample material was reserved for analysis. The tactile-visual soil analysis process was performed according to NBR 7250 [18].

From the survey results and soil characterization analyzes, important soil properties were obtained in order to allow the choice of the most appropriate type of foundation to be used. To this end, the foundations of the footing, caisson, excavated pile and auger cast pile were pre-selected for further examination. Considering the wide scope of the study, it is interesting to study these four because they are considered the most used in the regional technical environment and also differ in several aspects such as: executive method, productivity, costs and availability and advantages and disadvantages of each. The survey of these characteristics was made through studies of available bibliography as well as the research of companies of foundation of the metropolitan region of Goiânia.

Finally, the calculations of load capacity, resistance and sizing were made by the empirical methods of Alonso, Marcelo, Costa and Decourt-Quaresma using as parameters three load profiles with the values of 10 tons, 50 tons and 100 tons. The project aimed to vary the loads at these points and propose the best types of foundations to be used, justifying the choice. Then these three load profiles were evaluated for each soil profile analyzed by the drilling procedures, thus exchanging between the 4 types of foundations chosen in order to analyze which would be the most viable foundation type according to the effort exerted on them.

5. Results

In this chapter we will present the results obtained for the soil study and for the analysis of the load capacity of continuous and excavated props, tubing and piles, following the methodology described above. Also presented is the comparison between the 4 types of foundations in question. Finally, some pre-project economic feasibility studies for the study region are shown.

5.1. Soil analysis results

The research soil tests were conducted between May / 2017 and Dec / 2017, consisting of four SPT surveys followed by characterization of soil texture and type and moisture testing in the laboratory.

All tests were performed in the morning period between 8h and 12h. The variation in the date and location of the surveys showed interesting results regarding the characteristics of the study area, such as the considerable variation in the water level, which was, respectively, 5.80 m, 6.20 m, 6.90 m and 4, 45 m. This variation can be considered consistent with the rainy season of Aparecida de Goiânia - GO, which usually runs from November to April.

As for the moisture results, it is important to note that the samples do not represent the natural soil moisture from the washing depth as the amount of water in the site is artificially increased. In addition, the blows to advance the drilling also influence the results, since the tendency is for water particles to move away from the perforated site, which causes a decrease in moisture. Finally, it should be considered that bagged samples may lose moisture until they are placed in the greenhouse.

The moisture test results of the meter-by-meter soil samples of the four surveys performed are shown in Table 1 below. Considering the influencing factors already mentioned, it can be noted from the table that the data were consistent between one drill and another for the same drilling level. It is further noted that the final layers of the perforation present higher humidity since they are already near or past the water level found. Another pertinent observation is the higher moisture content for SPT 1 and SPT 4, since they were performed in post-rainy (May) and rainy (December) seasons, respectively.

Table 1. Moisture meter test results for each survey

Deep (m)	SP1	SP2	SP3	SP4
0	22,3%	9,9%	8,9%	18,3%
1	18,5%	20,0%	20,2%	28,6%
2	21,5%	13,0%	17,1%	35,3%
3	18,6%	21,1%	19,2%	23,8%
4	21,9%	25,2%	27,0%	25,6%
5	28,2%	22,5%	16,8%	23,0%
6	26,7%	23,0%	23,7%	23,6%
7	24,8%	20,5%	23,9%	25,2%
8	19,6%	27,4%	26,4%	27,1%
9	15,4%	24,0%	-	-

More generally, according to the observations of the tactile-visual tests meter by meter of the samples, three main soil types were found. They were classified as: reddish-clay and sandy-looking clay with interposed sand grains; brown sandy silt also with interposed sand grains and; dark brown silt with whitish crystals interposed with brilliant appearance. From this, based on the results of the classification of the first three surveys, of which the chosen points are aligned and with altimetric leveling between them, it was possible to draw the profile of the local soil, which is represented in Figure 1.

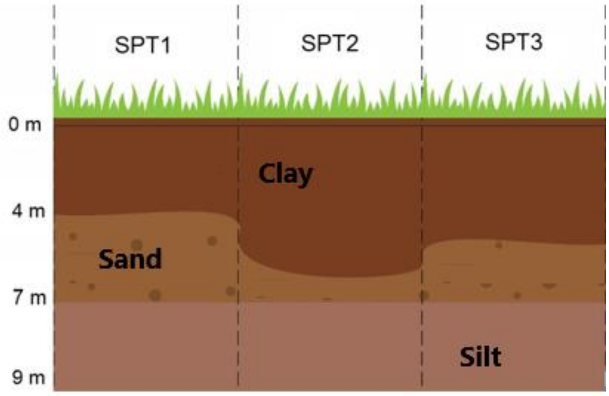

Figure 1. Soil Profile

Importantly, the first three surveys, as observed in the figure above, showed similar results regarding soil type. With regard to SPT4, the appearance of the soil was already silky within the first few meters of the test. This means that there was probably a process of earthmoving in the region studied, in which a cut was made in the region of the fourth point and grounding in the region of points 1, 2 and 3. This movement was confirmed by the direction of the campus.

The Penetration Resistance Index (N) values found in the four surveys are presented in Figure 2. In general, it can be said that the N values increased considerably from 6 m depth, except for the SPT4 that grows the resistance considerably already from 4 m. This may be due to earth moving at the site that differentiated the level at which the soil reaches resistance from one point to another.

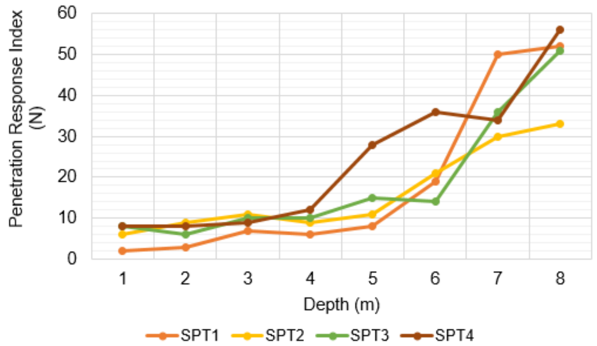

Figure 2. Penetration resistance indices meter by meter for each survey

5.2. Soil analysis results

From the survey results, the load capacities for the four types of foundations chosen were calculated. Firstly, Alonso's empirical method for footings was applied, it was obtained that for the loads involved in the design of a square footing foundation, the smallest width and length dimensions (in meters) required are as follows in Table 2 below.

Table 2. Bearing capacity and sizing results for footing

Footing (depth)	10 Ton	50 Ton	100 Ton
1 m	-	-	-
2 m	0.74 m	1.65 m	2.33 m
3 m	0.67 m	1.49 m	2.11 m
4 m	0.74 m	1.57 m	2.21 m
5 m	0.57 m	1.218m	1.81m

It is important to note that for the probes performed, the deeper the choice of the base point of the footing, the stronger the ground and the more reliable the Nspt results, so footings with a depth of 1 m were discarded as a constructive possibility. . Since the groundwater level is at a depth of 5.5 m below the surface, it makes a footing deeper than 5 m impossible. Analyzing the results obtained it is evident that the best option for footings with loads of 10, 50 and 100 tons would be the depth of 5 m, where it is necessary footings with minimum dimensions of 0.57 m x 0.57 m, 1.28 m x. 1.28 m and 1.81 m x 1.81 m, respectively. It is also found that the second best option for this case would be footings made at a depth of 3 m.

Regarding the sizing of caissons, the empirical method of Alonso was applied and it was found that, for the respective loads involved in the research, the smallest volumes (in cubic meters) required are as follows in Table 3.

Table 3. Load capacity and minimum volume for caissons

caisson (depth)	10 Ton	50 Ton	100 Ton
1 m	-	-	-
2 m	0,25 m³	1,07 m³	2,60 m³
3 m	0,21 m³	0,93 m³	2,08 m³
4 m	0,27 m³	1,24 m³	2,65 m³
5 m	0,22 m³	1,10 m³	1,93 m³

Analyzing the results obtained it is verified that the best option for caissons under loads of 10 and 50 tons would be the one with depth 3 m, where it is necessary to have a minimum volume of 0.212 m³ and 0.932 m³, respectively. For loads of 100 tons, the best option would be the depth of 5 m, which requires pipes with minimum volumes of 1.926m³.

Applying the Decourt-Quaresma empirical method for excavated piles and continuous propeller, it was found that for the loads involved in the design of this type of foundation, the minimum quantities of piles (in units) required are as follows excavated piles and continuous propeller, respectively, shown in Tables 4 and 5 below. It is important to point out that for the study, 40 cm diameter cuttings were established because they are more easily found in the commercial area of the metropolitan region of Goiânia.

Table 4. Load capacity and minimum amount unit for exc. pile

Excavated Pile (depth)	10 Ton	50 Ton	100 Ton
1 m	-	-	-
2 m	1 un	4 un	7 un
3 m	1 un	3 un	7 un
4 m	1 un	2 un	4 un
5 m	1 un	2 un	3 un
6 m	1 un	2 un	3 un
7 m	1 un	2 un	4 un

Table 5. Load capacity and minimum amount unit for auger cast pile

Auger Cast Pile (depth)	10 Ton	50 Ton	100 Ton
1 m	-	-	-
2 m	2 un	7 un	14 un
3 m	2 un	3 un	13 un
4 m	1 un	3 un	6 un
5 m	1 un	3 un	5 un
6m	1 un	3 un	5 un
7m	1 un	4 un	7 un

From the analysis of results it is possible to identify that taking into consideration the type of soil identified and the soundings used, a smaller amount of the excavated pile than the continuous propeller type is needed to support the same load of project. For continuous and excavated propeller pile foundations the most viable depth is 5 m, as it requires fewer piles to support the same load.

5.3. Preliminary cost study

Since the depth of 5 m was the one that obtained the most significant values of Nspt and also the one that required the least amount of material for all foundation types and the lowest number of piles, it was concluded that this would be the best possible depth for execution. Thus, for the depth of 5 m, Figure 3 represents the ratio of the amount of material volume in cubic meters required for each type of foundation to the three loads analyzed, 10, 50 and 100 tons.

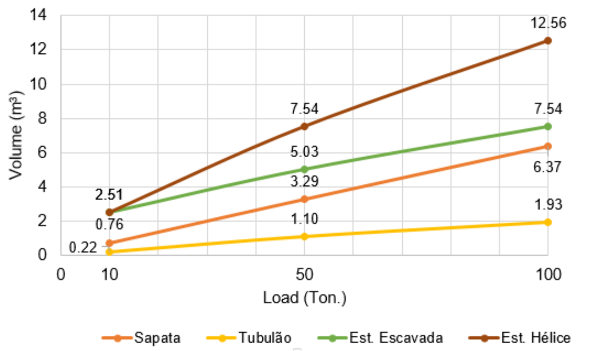

Figure 3. Material volume chart by foundation type at depth of 5 m

It can be observed that among the 4 types of foundations, the pipe-type pile is the one that needs the smallest volume for the three loads. By contrast, the continuous propeller type foundation is the one that needs the most volume. The propeller foundation type can total up to 6.4 times the required excavation volume for the caisson type. It is also found that although the continuous and excavated propeller piles have the same diameter, their volume is different. This is due to the increased coefficients in the Decourt-Quaresma methods, which meant that the 50 ton and 100 ton load profiles required more continuous propellers than excavated piles. Footing foundations have a volume 3.3 times larger than the pipe type and nearly half the volume of the continuous propeller pile.

The positive slope of the curves shows the directly proportional relationship between the load and the volume of material used, that is, the higher the point load, the more robust the foundation. Given this, it is noted that the slope of the curve for the pipe type is the lowest among the others, being 1.09 °, which shows that the variation of the size of the piece is smaller with the increase of the load when compared to the other types. . In contrast, the material volume of continuous propeller piles increases considerably with increasing load, with the slope of the curve being 6.37 °.

For the purpose of comparing preliminary cost of foundations, some companies in the region of Goiânia were consulted and a notion of cost for the local scenario was obtained. In addition, composition data from the Budget Price Compositions Table [19] were used.

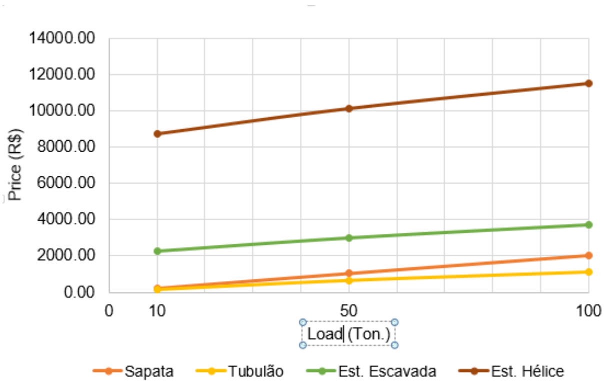

Figure 4. Approximate unit cost graph by foundation type

It is noteworthy that this preliminary cost survey did not consider the armature rates of the parts since this would require structural design with the punctual loads of each pillar. Nor did it need to include the cost of the shapes as the footings have a laying height of one meter deep and the soil in question is firm. Therefore, the approximate cost of material, labor and machinery needed to perform the pre-dimensioned parts in the survey was raised in economic terms.

Figure 5 below shows the comparison in terms of labor, equipment and material for each foundation type using the 100 tonne load profile and the depth of 5m. It is found that in the continuous propeller pile foundation, in unit terms, the mobilization of specific equipment to perform this type of foundation represents most of the total initial cost, about 70% of the total value. However, these percentages are reduced when demand is higher. For the footing type foundation, the material item is the most expensive among the others, which totals 75% of the total cost. Diverging from the previous ones, the pipe type had the most relevant cost of labor. Quotations were made in local market of the metropolitan region of Goiânia in January 2018.

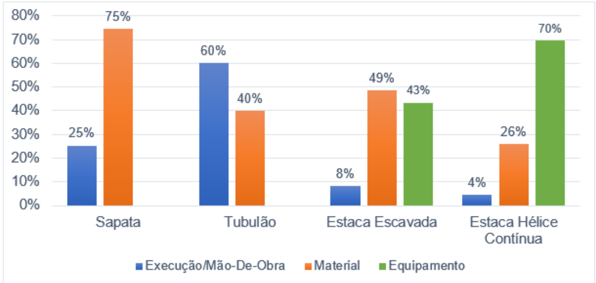

Figure 5. Cost comparison by foundation type

It is important to note that the cost analysis must take into account that the prices raised in this research are unitary and therefore a price and market reanalysis should be made when the required quantity of elements is dimensioned by means of the design calculation memorial. Foundations. For example, increasing the number of foundation elements may alter the interest of companies in the work, which may decrease the value of services, materials and machinery rental as the size of the work is larger.

5.4. Viability study

In unitary terms, among the 4 types of foundations analyzed against the 3 load profiles at the chosen depth of 5m. The caisson foundation was out of line with the others, up to 66x more economical than the 10-ton continuous propeller-type foundation, which was the least viable of them all.

The footing type foundation proved to be the second best cost option for a single unit sized to support the load profiles. However, in a project of such size as the study in question, countless units of footings, pipes and piles are necessary, which increases the possibility of footings of this dimension being overlapped, making this type of foundation impossible, in other cases. In other words, this type of foundation is not viable for the project.

Thus, the two most viable foundations to be built were caisson and excavated pile, and the caisson would be more economical. The piles are widely used in large works and even in medium works located on low resistance soil. However, when compared to other types, pile foundation needs specific equipment for its execution. Because the machinery employed and the skilled workforce are indispensable to ensure good service performance, piles are generally more expensive than caisson. However, while the cost of making the caisson is interesting, it is important to highlight the recurring danger of pit excavation which is a disadvantage of this type of foundation.

6. Conclusions

According to the results of the work, it can be concluded that the survey of the soil characteristics of the project area was consistent. The variation of soil type and Nspt of points 1, 2 and 3 with respect to point 4 proves that the region was grounded. The variation in humidity and water level is consistent with the climatic seasons throughout the year, as both humidity and level were lower in the dry seasons. As for the types of foundations studied, the caisson would be the most financially viable to run and, even with the job safety risks involved in drilling, still proves to be the best option when analyzing volume and cost charts.

Finally, it is believed that this feasibility analysis could be a basis for the final project at the time the building is implemented at the site studied. In addition, this work may serve as a basis for further on-campus academic research, as are the suggestions below.

7. Suggestion for future works

To complement the field studies of this work, it is recommended to drill more holes to the west of those already made to cover the entire expansion area of the Civil Engineering Technological Complex. Further, further soil analysis may be added to the study, such as prediction of repressions by means of supplementary SPT testing methods.

8. References

[1] BRADY, N. C.; WEIL, R. R. Elementos da Natureza e Propriedades dos Solos. Elements of Nature and Soil Properties [portuguese] 627 f. 3. ed. – Porto Alegre: Bookman, 2013.

[2] VARGAS, M. História das fundações: história da engenharia de fundações no Brasil .History of foundations: history of foundation engineering in Brazil. [portuguese] In: HACHICH, W.; FALCONI, F.F.; SAES, J.L.; FROTA, R.G.Q.; CARVALHO, C.S.; NIYAMA, S. (Org.). Fundações: teoria e prática. 2. ed. São Paulo: Pini, 1998. p. 34-50.

[3] FERREIRA, T. J.; GONÇALVES, P. M. A. S. Comparação do desempenho, em termos de recalque e custo, de fundações em estacas hélice contínua monitorada e em estacas de grande diâmetro escavadas com lama, em edifícios altos em Goiânia. Comparison of the performance, in terms of settlement and cost, of foundations in monitored continuous propeller piles and in large diameter piles excavated with mud, in tall buildings in Goiânia [portuguese] 2013. 79 f. Trabalho de Conclusão de Curso (Graduação) [work conclusion] - Bacharelado em Engenharia Civil. Universidade Federal de Goiás. Goiânia. 2013

[4] DAS, B. M. (1983) Princípios de Engenharia de Fundações. Founding engineering principles [portuguese] São Paulo: Cengage, 2016. 8ª edição. 306 p.

[5] CORDEIRO, D. D. Obtenção de parâmetros geotécnicos de areias por meio de ensaios de campo e de laboratório. Obtaining geotechnical parameters of sand through field and laboratory [portuguese] 2006. 198 f. Dissertação (Mestrado em Engenharia Civil) – Universidade Federal do Espírito Santo, Vitória, 2006.

[7] MILITITSKY, J.; CONSOLI, N. C.; SCHNAID, F. Patologia das Fundações. Foundations pathology [portuguese] São Paulo: Oficina de Texto, 2005. 207 p.

[8] ZACLIS, E. C. Projetista de Fundações. [Dezembro, 2011]. Revista techné. Entrevista concedida a Ana Paula Rocha. Disponível em: <http://techne.pini.com.br/engenharia-civil/177/artigo287894-1.aspx>. Acesso em 5 ago. 2017.

[9] SCARABEL, D. Estudo da Aplicação da NBR 6484-01 por construtoras de Campo Mourão e Região. 2012. 43 f. Trabalho de Conclusão de Curso (Graduação) – Curso Superior de Tecnologia em Materiais de Construção Civil. Universidade Tecnológica Federal do Paraná. Campo Mourão, 2012.

[10] PINTO, C.S., ABRAMENTO, M. Capítulo 2 – Propriedades dos Solos. Soil properties [portuguese] In: HACHICH ET AL. Fundações: Teoria e Prática. São Paulo: Pini, 1998. p. 51-118.

[11] CÂMARA, K.; R. da R., PEREIRA, A. C. Análise de perfis de sondagem SPT e caracterização geotécnica de solos do município de Natal-RN. 2005. 16p. Disponível em: <http://www2.ifrn.edu.br/ojs/index.php/HOLOS/article/viewFile/56/62> Acesso em 05 ago. 2017.

[12] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. Programação de sondagens de simples

reconhecimento dos solos para fundações de edifícios – NBR 8036, 1986.

[13] ASSOCIAÇÃO BRASILEIRA DE CIMENTO PORTLAND. Manual de Estruturas. Structural Manual [portuguese] São Paulo, 2003.

[14] Projeto e Execução de Fundações – NBR 6122, 2010.

[15]FERREIRA, T. R. Cálculo da capacidade de carga e o dimensionamento de sapatas isoladas utilizando planilhas eletrônica. 2013. 70 f. Trabalho de Conclusão de Curso (Graduação). Bacharelado em Engenharia Civil - Universidade Federal de Goiás, Catalão, 2013.

[16] SILVA JÚNIOR, A. C. Fundações: IFG. Foundations [portuguese] 01 mar. 2016, 10 dec. 2016. 20 p. Notas de Aula

[17]. Amostras de solo - Preparação para ensaios de compactação e ensaios de caracterização. - NBR 6457, 2016.

[18] Identificação e descrição de amostras de solos obtidas em sondagens de simples reconhecimento dos solos – NBR 7250, 1982.

[19] TCPO. Tabela de Composições de Preços para Orçamentos. São Paulo: Pini, 2017. 920 p.